Receiver Sensitivity:

Roadside Unit: -65 dBm/m^2

In-Vehicle Unit: -5 to -11 dBm/m^2

Multi-Access Technique: Yes. Proprietary HDLC

Message Transfer Capacity:

Roadside to Vehicle: 167 kbit/sec

Vehicle to Roadside: 267 kbit/sec

Permissible Operating Environment:

Physical Deployment / Set-Up Constraints: both side pole and over head mount OK

Coverage Zone: in a toll environment 3 x 4 meters

Cost of Infrastructure:

Deployment: approximately USD10,000 per lane

NRE:

Cost of In-Vehicle Equipment: from USD30.00 to 150.00

Targeted Market: Two-way communications between the vehicle and the roadside, primarily for automatic debiting applications (ETC), but used also for commercial fleet management and public transit monitoring process.

Market Share: Installations include:

Toll Collection: ASF Toulouse, France;AREA, Open System, Lyon, France; SAPRR Gannat, France; AREA, Closed System, Lyon, France; SAPN Normandie, Normandy Bridge, Tancarville Bridge, France; SPN A29, France; SAPN A14, France; Dartford River Crossing London, England; Mersey Tunnels Liverpool, England; Alesund/Giske Bruselshap Alesund, Norway; Trygg Tunnel A.S. Tromso, Norway; Europistas, Spain; Tate /Es Cairn Tunnel, Hong Kong; DARS, Torovo, Slovenia; Penang Bridge, Malaysia; Shan Alam Expressway, Malaysia; Zhuhai, China; AUSOL Buenos Aires Argentina; Tauern Autobahn Austria.

Access Control: Direccion General de Trafico, Madrid, Spain;

Border Crossing Shenzen Customs, China

Name of System: **PREMID™: EURO TAG™ TS3200**

Manufacturer: Saab-Scania Combitech Traffic Systems
Box 1063, S-551 10 Jonhoping, Sweden
Phone: 46 36 19 43 00
Fax: 46 36 19 43 01

Also/

21300 Ridgetop Circle
Sterling, Virginia 20166
Phone: (703) 406 - 7284
Fax: (703) 406 - 7224

Contact Person: Ove Salomonsson, Vice President (Sterling, Virginia)

System Description: This is an open protocol vehicle-to-roadside communications (VRC) system developed in coherence with PAMELA/ADEPT project under the European DRIVE program. It operates at 5.8 GHz and uses circular polarization. The communications link uses an active roadside reader and a reflective (backscatter) transponder in the vehicle. The system is fully compatible with the preliminary European standard for DSRC (Dedicated Short Range Communications) developed under Cen TC 278. Real "electronic pulse" Smart Cart capability available (Type IV transponder).

Detailed Specifications:

Operating Frequency: 5.795 to 5.805 GHz

Modulation Technique:
Roadside to Vehicle: Manchester encoded ASK
Vehicle to Roadside: FSK

Necessary Bandwidth:
Roadside to Vehicle: +/- 1.25 MHz
Vehicle to Roadside: 0.5 MHz per sideband x 2

Occupied Bandwidth: Two 5 MHz channels
Roadside-to-Vehicle: Not Provided
Vehicle-to-Roadside: Not Provided

Antenna Parameters:
Roadside Unit: 12 dB
In-Vehicle Unit: low-gain compact patch antenna 7 dB

Transmitted Power:
Roadside Unit: 2.0 W EIRP
In-Vehicle Unit: reflective backscatter

Receiver Sensitivity:

Roadside Unit: -100 dBm

In-Vehicle Unit: -40 dBm

Multi-Access Technique: Yes. TDMA, slotted ALOHA

Message Transfer Capacity:

Roadside to Vehicle: 500 kbit/sec

Vehicle to Roadside: 250 kbit/sec

Permissible Operating Environment:

Physical Deployment / Set-Up Constraints:

Coverage Zone:

Cost of Infrastructure:

Deployment: USD 15,000 per lane (estimate

NRE:

Cost of In-Vehicle Equipment: USD 30.00 to USD 150.00

Targeted Market: Two-way communication between the vehicle and the roadside, primarily for automatic debiting applications (ETC)

Market Share: Installations include:

Toll Collection: ASF Toulouse, France;AREA, Open System, Lyon, France; SAPRR Gannat, France; AREA, Closed System, Lyon, France; SAPN Normandie, Normandy Bridge, Tancarville Bridge, France; SPN A29, France; SAPN A14, France; Dartford River Crossing London, England; Mersey Tunnels Liverpool, England; Alesund/Giske Bruselshap Alesund, Norway; Trygg Tunnel A.S. Tromso, Norway; Europistas, Spain; Tate /Es Cairn Tunnel, Hong Kong; DARS, Torovo, Slovenia; Penang Bridge, Malaysia; Shan Alam Expressway, Malaysia; Zhuhai, China; AUSOL Buenos Aires Argentina; Tauern Autobahn Austria.

Access Control: Direccion General de Trafico, Madrid, Spain;

Border Crossing Shenzen Customs, China

Name of System: **TIRIS**

Manufacturer: Texas Instruments
TIRIS Sales and Application Center
13020 Floyd Road
Dallas, Texas 75243
Phone: (214) 917 - 1462
Fax: (214) 917 - 1440

Contact Person: Dave Newman
(214) 917-1460

System Description: TIRIS is a DSRC system based on backscatter technology. The AM modulated signal is imposed with an FM subcarrier at 900 kHz for the uplink (vehicle to roadside) channel. Tags are available in read-only or read/write versions. Versions are also available for dash mounting or exterior (license plate) mounting.

Detailed Specifications:

Operating Frequency: 915 MHz (902 - 928 MHz)

Modulation Technique:
Roadside to Vehicle: Manchester II Encoded ASK
Vehicle to Roadside: ASK with FSK subcarrier: Mark: 1200 kHz sq. wave
Space: 600 kHz sq. wave

Necessary Bandwidth:
Roadside to Vehicle: Not Provided
Vehicle to Roadside: Not Provided

Occupied Bandwidth:
Roadside-to-Vehicle: < 3 MHz
Vehicle-to-Roadside: < 3 MHz

Antenna Parameters:
Roadside Unit: Various options.
In-Vehicle Unit: 90 deg. field of view typical. Etched PC board antenna.

Transmitted Power:
Roadside Unit: 100 mW to > 1.0 W
In-Vehicle Unit: N/A (backscatter)

Receiver Sensitivity:
Roadside Unit: Proprietary

In-Vehicle Unit: 500 mv/m

Multi-Access technique: California Title 21 compliant / Access and Silence. No specific multi-access technique. It does use a pulse amplitude technique for lane discrimination.

Message Transfer Capacity:
Roadside to Vehicle: 300 kbps (including coding)
Vehicle to Roadside: 300 kbps (including coding)

Permissible Operating Environment: All weather operation.

Physical Deployment / Set-Up Constraints: Typically an overhead antenna is installed to monitor a single lane of traffic. Multiple lane coverage includes readers for each lane with synchronized pulse that the tag uses for lane discrimination (simple amplitude comparison).

Coverage Zone: Various antenna beamwidths and transmit power levels available. Typical single lane deployment has an antenna mounted 18 feet above the roadway with 22, 30, 35 and 40 degree beamwidths.

Cost of Infrastructure: Proprietary
Deployment:
NRE:

Cost of In-Vehicle Equipment: Proprietary

Targeted Market: Electronic Toll Collection (ETC), Electronic Traffic and Toll Management (ETTM), Parking / Access Control

Market Share: Proprietary

<u>References:</u>

Information received from Dave Newman (filled out above template) January 24, 1996.

Sales brochures on the TIRIS system.

Sharpe, C. A., "Wireless Automatic Vehicle Identification," *Applied Microwave & Wireless*, Fall 1995, pp. 32-58.

Name of System: XCI: RFID Systems for Toll Collection

Manufacturer: XCI, Inc.
Automatic Identification
6315 San Ignacio Ave.
San Jose, CA 95110
Phone: (408) 281-6612
Fax: (408) 578-4102

Contact Person: Karen Vorster, Sales Manager

System Description: XCI produces a variety of passive automatic identification systems for the toll collection (ETTM), factory automation, access control and automatic vehicle identification (airports) markets. The products manufactured by XCI include RF readers, reader controllers, and transponders. The transponders are passive, using Surface Acoustic Wave (SAW) technology. The toll collection transponders are referred to as the Commute Tag (IWT-1) and the Commercial Tag (IDR001). These transponders, in conjunction with the RF readers and read controllers, enable accurate identification at vehicle speeds up to 150 mph using very low power. The XCI system does not require FCC licensing due to the low power utilized by the reader.

Detailed Specifications:

Operating Frequency: 915 MHz

Modulation Technique:
Roadside to Vehicle: FM chirp
Vehicle to Roadside: Delay modulation

Necessary Bandwidth:
Roadside to Vehicle: 20 MHz
Vehicle to Roadside: 20 MHz

Occupied Bandwidth:
Roadside-to-Vehicle: Not Provided
Vehicle-to-Roadside: Not Provided

Antenna Parameters:
Roadside Unit: 8 dBi patch linear polarization
In-Vehicle Unit: 3 dBi dipole linear polarization

Transmitted Power:
Roadside Unit: 0.05 W, peak power
In-Vehicle Unit: passive, reflective

Receiver Sensitivity:
Roadside Unit: -115 dBm
In-Vehicle Unit: N/A

Multi-Access Technique: None. By spatial isolation only.

Message Transfer Capacity: Instantaneous data rate of 20 Mbps

Permissible Operating Environment: All weather operation.

Physical Deployment / Set-Up Constraints: The system is modular and easy to install. There are no set-up constraints, the reader is simply mounted in an overhead position. There is very little problem with "cross-talk" as the readers are software programmable to correct.

Coverage Zone: Range from reader to tag is 15 feet typically, and 20 feet maximum.

Cost of Infrastructure: Not Provided.
Deployment:
NRE:

Cost of In-Vehicle Equipment: The Commute windshield transponder has a $25 list price. The Commercial rugged transponder has a $28 list price.

Targeted Market: Electronic Toll Collection (ETC), Electronic Toll and Traffic Management (ETTM), factory automation, access control and automatic revenue collection, and curbside control.

Market Share: Used in the San Francisco Bay Area Rapid Transit (BART) system to provide improved access for disabled persons. Also used in Chrysler automobile production to electronically tag each vehicle with its VIN number. Other sample installations include:
Toll Collection: E-470 Denver, Colorado
Factory Automation: Hyundai, Freightliner, Chrysler, Honda, Bethlehem Steel, and EDS
Access Control: Federal Reserve Bank, Stanford University, Park&Service, E-470 toll road, Bay Area Rapid Transit, and Maytag
Automatic Vehicle Identification: PG&E, San Jose International Airport, Sky Chefs Chicago O'Hare International Airport, Kennedy International Airport, and LaGuardia International Airport

References:
Sales and advertising literature.
"Radio Frequency Identification (RFID)," Market Study, Air Force Automatic Identification Technology (AIT) Program Management Office, May 1995.
Fax received from Karen Vorster, Sales Manager, XCI, Inc., on January 26, 1996.

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Appendix B: AEI and CVO Tag Usage

As quoted from the CVO requirements document[1], 'It is assumed that several types of tags will exist and that a vehicle may have to use more than one tag in order to participate in ITS. For example, a private vehicle will able to use a single tag for all appropriate and desired ITS applications (i.e., electronic toll collection, in-vehicle signing). However, a commercial vehicle will employ a more capable power unit tag that supports both private vehicle as well as commercial vehicle functionality. Furthermore, CVO will require the use of multiple types of tags. For example (as shown in Figure 1), two classes of tags, a read/write and a read-only tag, would be used to support different functions. The read/write class would be used for the power unit. The read only tag supports fleet and freight management oriented applications such as automatic equipment identification (AEI) and freight tracking."

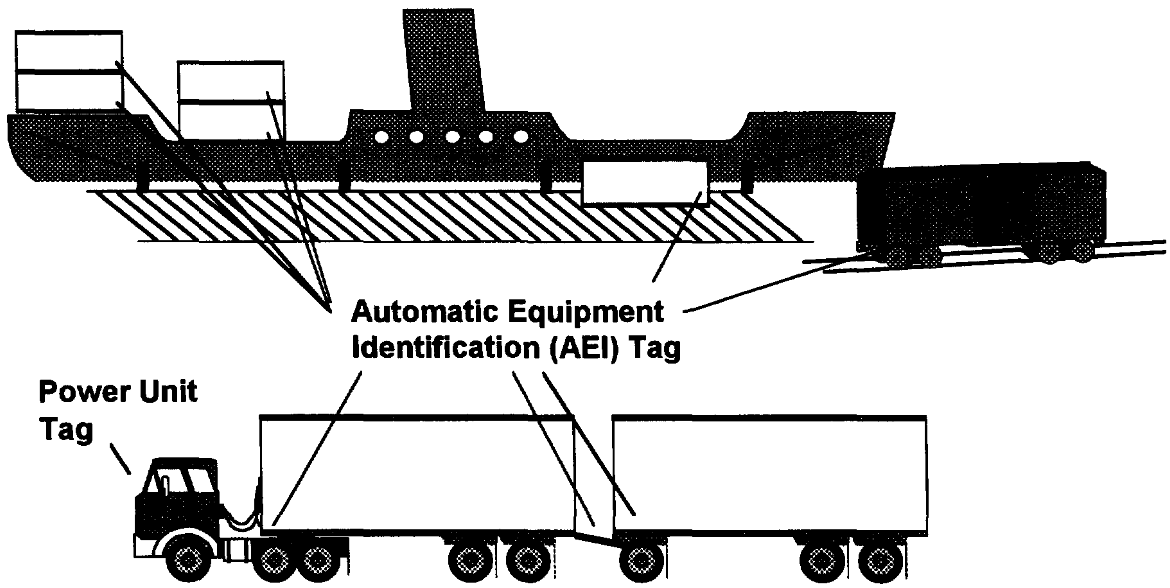

Figure 1 Use of Multiple DSRC Tag Types for CVO

References

[1] Yuan, R, Johns Hopkins University Applied Physics Laboratory, Draft CVO Dedicated Short Range Communications (DSRC) Requirements for ITS Version 2.0, April 1996.

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APPENDIX C: SPECTRUM REQUIREMENTS FOR A DEDICATED SHORT RANGE COMMUNICATIONS (DSRC) CHANNEL

1.0 Introduction

This appendix presents an assessment of the spectrum required to support a single DSRC channel. There are still many options for the selection of the air interface specification and this section will describe the spectrum requirements for one of the most demanding of these options. The purpose of this section is not to support selection of a particular air interface, but rather to explore the spectrum needed by an example air interface.

The candidate air interfaces include the draft ASTM standard, the European DSRC prestandard using the default parameters, a modified European DSRC prestandard, and the European DSRC prestandard using higher optional data rates. The European DSRC prestandard modified to meet the estimated US data rate is the one that has the most demanding spectrum requirement. By basing the spectrum requirement calculation on the most demanding option, any of the options can be selected for use if compromises in reuse distance, transponder complexity, message content, or range are determined to be the best course of action.

The default parameters for the European DSRC prestandard [1] result in a 500 kBit/s downlink data rate and a 250 kBit/s uplink data rate. Currently, the US proposed rates are 600 kBit/s for downlink and uplink. If the European DSRC prestandard were used as a basis for a US standard, the US requirement could be met by scaling the frequency parameters of the European prestandard and employing an option in the standard to carry data in both subcarrier channels. In addition, the US standard could use a preamble (similar to the European standard) that establishes the parameters from a list of options (including the data rate) for each communications session. This would allow a vehicle to use the default parameters for an application that does not require the highest data rate and use the highest data rate for more demanding applications in other locations. This could allow initiation of DSRC operations using the default data rates for applications that need only modest data rates and the use of higher data rate options when more demanding applications are deployed. The default parameters can be implemented with various options in different communications sessions while using the same equipment in each session.

Section 2.0 describes the parameters in the European prestandard for DSRC and how it might be modified to meet the US requirements. Section 3.0 describes the parameters for the proposed US DSRC standard. Section 4.0 presents an analysis of the spectrum requirements for the proposed US DSRC standard derived from the European prestandard.

2.0 Modifying the European Prestandard for DSRC

The European prestandard for DSRC presents the requirements for a vehicle-to-roadside communications system. The European DSRC systems assume a half duplex communications scheme where the roadside unit (RSU) or beacon transmits the data to the vehicle and then provides a tone for the uplink. The onboard unit (OBU) in the vehicle modulates the tone from the beacon and reflects the signal back to the beacon for the uplink communications. This communications scheme minimizes the RF components in the OBU which in turn reduces the complexity and cost of the OBUs.

The primary source of information for spectral analysis of the European DSRC systems is the latest prestandard for the DSRC physical layer [1]. The downlink is defined in the European prestandard as an amplitude-shift-keyed (ASK) signal. The default encoding of the downlink data is FM0. FM0 encoding is defined as a transition in the signal at the beginning and end of each bit plus an additional transition in the middle of the "0" bit. An alternative data encoding for the downlink is NRZI. NRZI encoding is defined as no transition at the beginning of a "1" bit, a transition at the beginning of a "0" bit, and constant level within a bit. The default data rate for the downlink is 500 kBit/s. The primary downlink parameters from the prestandard that are required to assess the spectrum are listed in Table 1.

Table 1. European DSRC Downlink Parameters

Parameter	Default Value	Optional Values
Modulation	Two level amplitude modulation	None
Modulation Index	0.5 . . . 0.9	None
Data Coding	FM0	NRZI
Bit Rate	500 kBit/s	31.25 kBit/s 62.5 kBit/s 125 kBit/s 250 kBit/s 500 kBit/s 1000 kBit/s

The optional values listed allow applications that use lower data rates to use lower performance receivers; tolerate more noise, because they can use a smaller IF bandwidth; and obtain closer distances between adjacent channels, due to more signal attenuation between occupied spectra.

The uplink described in the European DSRC prestandard uses M-ary phase shift keying (M-PSK) on one or both of two subcarriers. The default uplink parameters specify that the data are to be transmitted on only the upper subcarrier or the same data are to be transmitted on both subcarriers simultaneously. The prestandard allows for different data to be transmitted on each subcarrier as an option. The subcarrier signals are synchronized with the data sequence such that the transitions of the data coincide with the transitions of the subcarrier. The data are encoded using the NRZI protocol and the default data rate is 250 kBit/s. Table 2 lists the primary uplink parameters from the European prestandard.

Table 2. European DSRC Uplink Parameters

Parameter	Default Value	Optional Values
Subcarrier Frequencies	1.5 MHz and 2.0 MHz	None.
Use of Subcarrier Bands	Same data on both bands or data only on upper band will be allowed for default	• Same data in both • Data only in upper • Different data in each
Subcarrier Modulation	M-PSK	None.
Data Modulation Order	M = 2	M = 2 M = 4 M = 8
Modulation on Carrier	Multiplication of modulated subcarrier with carrier	None.
Data Coding	NRZI	None.
Symbol Rate (per subcarrier)	250 kBit/s	Bit Rate: 31.25 kBit/s 6.25 kBit/s 125 kBit/s 250 kBit/s 500 kBit/s 750 kBit/s

Simply scaling the European prestandard parameters results in a US DSRC system with a default downlink data rate of 600 kBit/s and a default uplink data rate of 300 kBit/s. To achieve a default uplink of 600 kBit/s, the default options for the uplink must be changed. The European DSRC default uplink either transmits the same data on both uplink subcarriers or transmits data only on the upper (2.0 MHz) subcarrier. The US DSRC system can have a default 600 kBit/s uplink by selecting the default option that different data is transmitted on each subcarrier. Since each subcarrier can transmit 300 kBit/s, the result is a total uplink data rate of 600 kBit/s.

There are other options for modifying the European DSRC prestandard to achieve 600 kBit/s on the uplink. The uplink default data modulation order could be changed to 4 (QPSK). Another option would be to combine the two uplink subcarrier into a single subcarrier and double the baud rate of the uplink. Either of these options are feasible alternatives for doubling the uplink data rate. For this analysis, however, changing the default use of the two subcarrier bands was assumed.

3.0 Proposed US DSRC Based on European Prestandard

The data rate requirements for a US DSRC system are discussed in the main body of this report. These estimated data rates are required to support all the DSRC functions expected in the US Intelligent Transportation Systems (ITS) National Architecture. The uplink and downlink data rates estimated are both 600 kBit/s. This data rate is slightly higher than the European prestandard default downlink data rate and more than twice the default uplink data rate. However, the estimated US required data rate is within the limits of the optional parameters for the European prestandard.

For this analysis, the parameters for the US DSRC system are derived by simply scaling the European parameters by 6/5. For example, the European prestandard assumes a 5 MHz bandwidth and therefore the US DSRC bandwidth will be 5 MHz $\times$ 6/5 = 6 MHz. The US DSRC modulation formats and data encoding are assumed to be the same as those in the European prestandard. The resulting parameters for the US DSRC downlink and uplink are listed in Tables 3 and 4, respectively.

Table 3. Assumed US DSRC Downlink Parameters

Parameter	Default Value	Optional Values
Modulation	Two-level amplitude modulation	None
Modulation Index	0.5 . . . 0.9	None
Data Coding	FM0	NRZI
Bit Rate	600 kBit/s	37.5 kBit/s 75 kBit/s 150 kBit/s 300 kBit/s 600 kBit/s 1200 kBit/s

Table 4. Assumed US DSRC Uplink Parameters

Parameter	Default Value	Optional Values
Subcarrier Frequencies	1.8 MHz and 2.4 MHz	None.
Use of Subcarrier Bands	Different data transmitted on each subcarrier for default	• Same data in both • Data only in upper • Different data in each
Subcarrier Modulation	M-PSK	None.
Data Modulation Order	M = 2	M = 2 M = 4 M = 8
Modulation on Carrier	Multiplication of modulated subcarrier with carrier	None.
Data Coding	NRZI	None.
Symbol Rate (per subcarrier)	300 kBits	Bit Rate: 37.5 kBit/s 75 kBit/s 150 kBit/s 300 kBit/s 600 kBit/s 900 kBit/s

4.0 Spectrum of Proposed US DSRC: 600 kBit/s Downlink, 600 kBit/s Uplink

Each of the spectrum plots depicted in this section was generated by modeling the appropriate waveform in MathSoft's Matlab version 4.0. The data rate was modeled as a sequence at 1 Bit/s and then encoded as defined in Tables 3 and 4. The appropriate modulation was then applied. The spectrum was generated by calculating 20 times the log of the magnitude of the Fast Fourier Transform (FFT) of the modulated waveform. The plots were scaled in frequency to the appropriate data rate and then shifted such that the center frequency was 0 Hz. Any filtering that was used assumed an ideal bandpass filter.

The proposed US DSRC air interface is basically identical to the European DSRC prestandard system scaled to accommodate the higher data rates. The only significant difference assumed is that the uplink subcarriers carry different information and thus an uplink data rate of 600 kBit/s can be achieved. Note that the US system can operate in a default mode with 300 kBit/s uplink data being transmitted on both subcarriers or the upper subcarrier only, just like the European system. During a transaction between the RSU and OBU, the system can elect to switch to different data on each uplink subcarrier when necessary. This option is allowed in the European protocol and would thus maintain another similaritiy between the proposed US DSRC system and the European DSRC prestandard system.

Figures 1 - 3 depict the spectra of the proposed US DSRC system (with the carrier frequency normalized to 0 Hz). Each link assumes the 22-bit data sequence (0 1 0 1 0 0 1 1 0 0 0 1 1 1 0 0 0 0 1 1 1 1). Figure 1 depicts the ASK downlink which is 600 kBit/s data that is FM0 encoded and then binary ASK modulated with an 0.7 modulation index. Note that the mainlobe of the spectrum is contained within ± 1.2 MHz of the carrier. The bandwidth is determined primarily by the data rate and not the particular data sequence chosen. Figure 2 depicts the spectra of the uplink subcarriers at 1.8 MHz and 2.4 MHz. Each of the uplink subcarriers transmit data at 300 kBit/s with NRZI encoding and BPSK modulation. Note that the main lobes of the subcarrier spectra are 600 kHz wide and thus do not overlap with each other or the downlink main lobe.

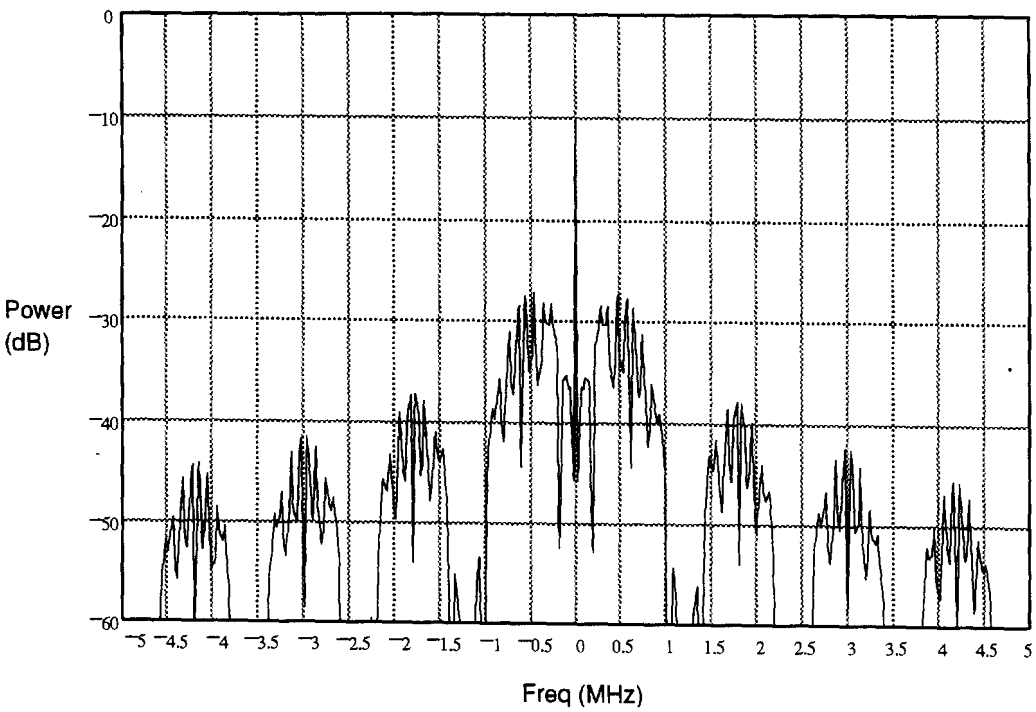

Figure 1. Spectrum of the Proposed US DSRC Downlink

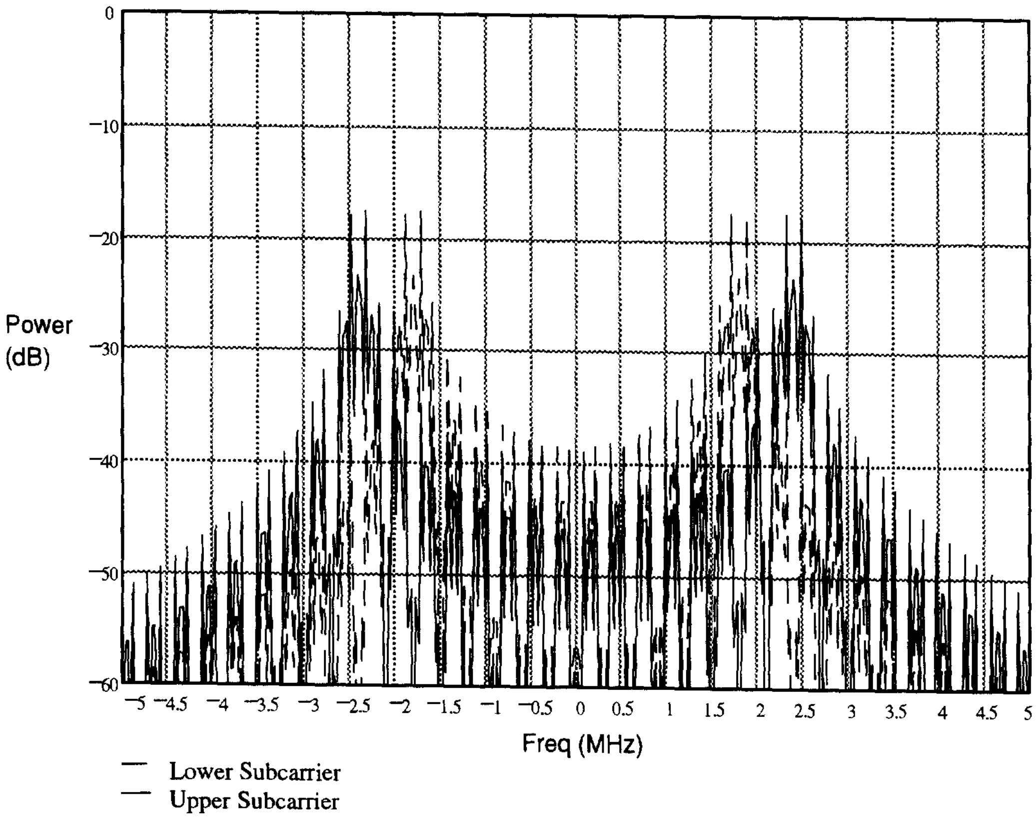

Figure 2. Spectrum of the Proposed US DSRC Uplink

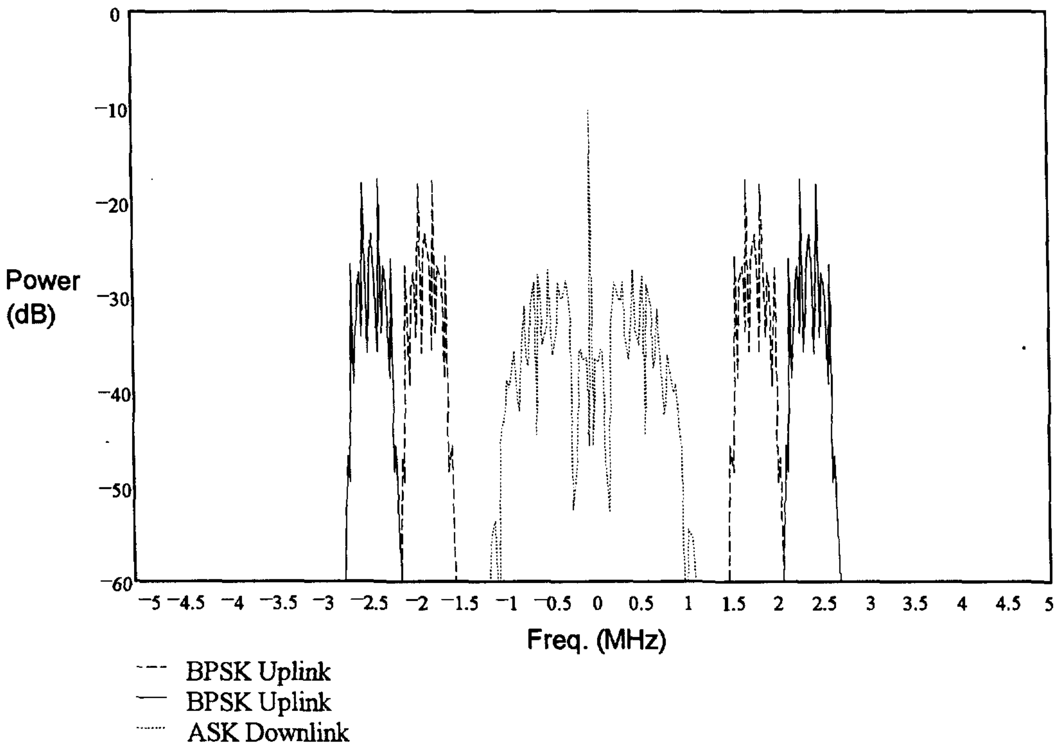

Figure 3. Composite Spectrum of the Proposed US DSRC Downlink and Uplink

Figure 3 was developed by filtering the uplink and downlink spectrums with bandpass filters such that only the mainlobes of the spectrums are transmitted. The downlink bandpass filter in the RSU allows only ± 1.2 MHz of the center frequency to pass through and be transmitted. Each of the subcarriers is filtered with a 600 kHz wide bandpass filter prior to being mixed with the RSU tone. The plot in Figure 3 assumes ideal filtering. The design of the actual filters used will determine the level of isolation between the communication bands.

Note that the entire spectrum of a US DSRC channel can be contained within the 6 MHz bandwidth. There is an approximately 300 kHz guard band on each side of the channel to allow for filtering to reduce adjacent channel interference. There is also a 300 kHz guard band between the downlink spectrum and the spectrum of the uplink lower subcarrier which again can be used to increase isolation (reduce interference).

5.0 Conclusions

The spectral analysis presented above demonstrates that the proposed US DSRC system with 600 kBit/s uplink and downlink data rates can be achieved within a 6 MHz bandwidth by scaling the European standard and using one of the uplink optional parameters. This result indicates that any of the less demanding air interfaces can be implemented within this 6 MHz bandwidth. These optional interface include the draft ASTM standard, the unmodified European DSRC prestandard, and the European DSRC prestandard using higher optional data rates.

However, in order to use another air interface, compromises would need to be made in reuse distance, transponder complexity, message content, or range.

References

[1] "European Prestandard: Road Traffic and Transport Telematics (RTTT) Dedicated Short-Range Communications (DSRC): DSRC Physical Layer using Microwave at 5.8 GHz," Ref. No. prENV 278/9/#62 Version 4.0 1995, drawn up by CEN TC278 WG9 SG.L1 and Project Team M018/PT06, October 1995.

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APPENDIX D

DEDICATED SHORT RANGE COMMUNICATIONS (DSRC)

REUSE DISTANCE CALCULATIONS

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DEDICATED SHORT RANGE COMMUNICATIONS (DSRC)

REUSE DISTANCE CALCULATIONS

June 1996

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